JVIB

February 2005 • Volume 99 • Number 2

An Evaluation of Substrates for Tactile Maps and Diagrams: Scanning Speed and Users' Preferences

Sandra Jehoel, Simon Ungar, Don McCallum, and Jonathan Rowell

Abstract: This study evaluated the relative suitability of a range of base materials for producing tactile maps and diagrams via a new ink-jet process. The visually impaired and sighted participants tactilely scanned arrays of symbols that were printed on seven substrate materials, including paper, plastic, and aluminum. In general, the rougher substrates were scanned faster than the smoother substrates, and the majority of participants preferred the rougher substrates over the smoother ones.

The research reported here was funded by a grant from the Engineering and Physical Sciences Research Council in the United Kingdom and by the Enterprise and Innovation Office of Anglia Polytechnic University. The authors are indebted to Lesley Wells and the staff and students at Royal National College, Hereford, for facilitating and participating in this research. They are grateful to the Department of

Materials Science and Metallurgy at the University of Cambridge and to project collaborators from the Ordnance Survey; Royal National Institute for the Blind; National Centre for Tactile Diagrams; and Royal National College, Hereford, for providing materials and for comments on an earlier version of this article.

Tactile maps and diagrams are raised-line images that are used to convey information in graphic formats to people who are visually impaired (that is, are blind or have low vision). This information can be of great importance to visually impaired people because it allows them to study, work, and live more independently. Tactile images are produced using a variety of substrates (background materials), depending on the production method that is used (Horsfall, 1997; Morley & Gunn, 2002). For example, the microcapsule process uses cloth-embedded paper that contains heat-activated microcapsules, embossed graphics are produced using paper, thermoform uses thermoplastic polymers, and screen printing is done on a wax-based paper.

Previous studies have attempted to measure differences in map-reading performance for maps that have been produced using various methods. Dacen-Nagel and Coulson (1990) studied map-reading performance on maps of several levels of complexity that were

produced by four methods. They found that microcapsule maps were explored the fastest and received the most favorable comments, followed by multitextural maps and maps that were produced by letterpress plates, whereas thermoform maps yielded the slowest response times and the most unfavorable comments. Pike, Blades, and Spencer (1992) investigated the map-reading performance of children with visual impairments using microcapsule and thermoform maps. They found no significant differences in performance while reading the two types of maps. As Perkins (2002) pointed out, difficulties may arise when researchers try to compare different production methods in this way. First, it is difficult to obtain equal levels of complexity over pseudo-maps. Second, in most production methods, the symbols consist of the same material as the substrate, so it is not possible to vary the substrates and to keep the symbols constant across substrates.

In the study reported here, the two potential problems just mentioned were avoided. First, abstract symbol matrices were used, ensuring equal levels of complexity across trials. Second, the displays were constructed using a new technology, the TIMP tactile inkjet printer, which can print tactile images in polymer on a large variety of substrates. This printer uses a 500-nozzle, 180 dots-per-inch, piezo, drop-on-demand industrial printhead. Ultraviolet cured ink drops of 80 picoliters are built up in a multilayer process. For a detailed description of the printing

process, see McCallum & Ungar, 2003. This technology allowed us to compare a range of substrates and to keep other factors constant.

The aim of this study was to determine which substrates or types of substrates are the most suitable for producing tactile maps and diagrams. The suitability of a substrate can be defined in two ways. First, substrates may vary in the ease with which information can be extracted. This variation may be caused by differences in contrast between the substrate and the symbols that are printed on it. As Keates (1982) suggested, visual detection of a symbol depends on the size of the symbol and the contrast with the background on which it appears. Likewise, tactile detection may depend on a similar relationship between the symbol and the substrate. Properties of the material, such as roughness and absorbency, may also affect the ease with which information can be extracted by influencing the speed at which the user can move his or her fingers.

Numerous studies have explored the perception of roughness. For example, Lederman (1974, 1981, 1983) and Lederman and Taylor (1972) found that the width of the groove and the force that the finger exerts were the most important factors in the perception of the roughness of gratings. Heller (1989) did not find differences in judgments of smoothness by sighted and blind participants or between passive (in which a stimulus is applied to a static skin surface) and active

(in which a stimulus is engaged with by a moving skin surface) touch. These studies suggested that observers are able to differentiate among materials over a range of levels of roughness.

The second aspect of the suitability of substrates is related to users' preferences. Ekman, Hosman, and Lindström (1965) reported that the participants in their study preferred smoother, rather than rougher, surfaces among seven surface textures, ranging from paper to coarse sandpaper. However, in a recent survey of users of tactile maps (Rowell & Ungar, 2003), in which the participants were presented with identical maps (produced by inkjet printing, as in the present study) on two substrates, all the participants who commented expressed a preference for the rough surface over the smooth one. In this study, we investigated which substrates allow for the easy extraction of information in terms of the relative time taken to identify symbols and the relationship between preference and roughness in the hope of clarifying previous findings.

Method

Participants

Of the 29 participants in the study, 14 were sighted and 15 were visually impaired. Nine of the 10 male visually impaired participants and 5 female visually impaired participants, who ranged in age from 17 to 50 (mean age of 29.8 years), were recruited at the Royal

National College in Hereford, England, and 1 man who was blind (aged 39) was recruited at Anglia Polytechnic University in Chelmsford. Eight of the visually impaired participants were totally blind, and 7 had some form of residual vision; 10 of the 15 were frequent braille users. The sighted participants (4 men and 10 women), aged 17–49 (mean age of 25.1 years), were recruited at the University of Surrey.

Materials

After we crossed seven types of substrates with seven arrays of symbols, we constructed 49 experimental displays. The seven substrates were rough plastic (high-impact polystyrene with a rough finish), smooth plastic (high-impact polystyrene with a smooth finish), rough paper (the reverse side of Avery Dennison SU5134), smooth paper (Avery Dennison SU5142), microcapsule paper (Zychem), textured PVC film (Braillon) and standard-grade aluminum. Displays were printed using the TIMP tactile printer. Each substrate was backed by a rigid sheet of medium-density fiberboard and measured 29.7 by 21.2 centimeters (11.7 by 8.3 inches).

Each array measured 25.8 by 19.2 centimeters (10.2 by 7.5 inches) and contained nine rows of eight symbols. Five shapes were used that had been found to be highly discriminable (Rener, 1993): an outline circle, an ellipse, a square, an inverted T, and an inverted V. The T and V in Rener's set were turned 180 degrees to

prevent their association with print letters. Four of the shapes were randomly distributed over nine rows of eight symbols. The fifth shape, an inverted V, was used as the target symbol. Eight targets were randomly distributed across the first eight rows. The ninth row contained zero, one, or two target symbols to prevent counting; this row was disregarded in the data collection. Figure 1 presents an example of the displays. Symbols were 8 by 8 millimeters (.315 inch by .315 inch), except for the ellipse, which was 5.5 by 11 millimeters (.216 by .433 inch), which is a size at which symbols have been shown to be readily identifiable and discriminable (Horsfall & Vanston, 1981). The width of the line was 1.3 millimeters (.05 inch), and the height was nominally 340 micrometers (.0134 inch). This height is in the middle to lower ranges of common heights for tactile and braille features that are produced by other methods and is well above the thresholds of size and elevation for identifying tactile symbols (Jehoel, Ungar, & Rowell, in preparation). Time and the input of materials were minimized at this height, while readability was maintained. On the left side of the page, horizontal lines were printed that enabled the participants to keep track of their position on the display.

Procedure

The experiment consisted of a tactile search task and a preference-ranking task. The sighted participants and those with residual vision were blindfolded during both

tasks. The search task was performed first. The participants were asked to scan the arrays of symbols as quickly and as accurately as possible, proceeding from the top left corner to the bottom right corner, and to give a verbal response when encountering a target symbol. They were asked to use their right hand to explore the rows of symbols and their left hand to keep track of their position by placing it on one of the horizontal lines to the left of each row. After a practice trial, 14 displays were presented in two sets of 7, each set containing all the substrates and all the arrays. The two sets were replications and did not differ in any meaningful way. The order of substrates and arrays was pseudo-random, to ensure that the participants explored each substrate twice with a different array. A digital video camera was used to record the amount of time that was needed to complete the eight by eight arrays and to record errors (false negatives and false positives).

After they completed the search task, the participants were asked to rank all the substrates in order of preference. They received all seven substrates in a pile presented in random order and lined them up on a table in order of preference. We did not suggest any basis for ranking, but simply asked the participants to order the substrates on the basis of how much they liked each one. After the ranking task, the participants were asked to explain the basis for their judgments.

Results

Errors

Overall, the participants made few errors in identifying the target symbols. A total of 464 target symbols (29 participants × 8 target symbols × 2 presentations of a substrate) were explored on each substrate. Table 1 shows the total number of errors. Since the number of errors was small and there was no evidence of any relationship between the type of substrate and the number of errors, the errors were disregarded in further data analyses.

Roughness

The data suggested that the roughness of a substrate played an important role in both the participants' scanning speeds and rankings of preference. The average roughness of the substrates was measured with a Wyko RS-2 Interferometric Surface Profilometer, with a lateral resolution of 1 micron and a depth resolution of 5 nanometers, which generated detailed topographical information by scanning an optical beam over a material and analyzing the interference of reflected fringes. Figure 2 shows the roughness values for each substrate and how these values were related to the participants' scanning time.

Time

The search time was measured from the moment the

participants touched the first symbol in the display until they left the last symbol in the eighth row (M = 77.6 seconds, SD = 33.5 seconds). The visually impaired participants performed the task faster than did the sighted participants (M_{VI} = 56.8 seconds, SD = 23.2 seconds, and $M_{sighted}$ = 99.8 seconds, SD = 28.0 seconds). The standard deviation in the mean search time between the groups of participants was large. However, the standard deviation within the groups of participants was considerably smaller (mean SD = 10.2 seconds), which indicates that although the mean scores differed greatly between the two groups of participants, all the participants scored within certain limits from their own mean. Therefore, to be able to compare the means of all the participants, we standardized each participant's scores by converting them to *z*- scores, which indicate the number of standard deviations of each time measurement from the participant's own mean score. Table 2 shows the mean *z*-scores for all the substrates.

A mixed-measures analysis of variance (ANOVA), with visual status (the visually impaired versus the sighted participants) as a between-subjects factor and substrate as a within-subjects factor, showed that the type of substrate had an overall effect on search time ($F(6, 162) = 8.03$, $p < .01$). The main effect of visual status ($F(1, 27) = 0.00$, $p = .99$) and the interaction effect ($F(6, 162) = 0.19$, $p = .98$) were not significant. Since there were no time differences between the two

groups of participants, the data for the two groups were collapsed for further analysis.

Pairwise comparisons indicated which substrates differed significantly in search time ($p < .05$). The participants scanned aluminum and smooth plastic more slowly than Braillon, smooth paper, rough paper, and microcapsule paper. They required more time to scan rough plastic than rough paper and microcapsule paper and more time to scan Braillon than rough paper and microcapsule paper. Figure 3 presents these differences diagrammatically, with connecting lines indicating significant differences in search time among the substrates.

Preferences

The participants' preferences for substrates, as indicated by their responses to a specific question about the basis of their preference rankings, showed two distinct patterns (one participant did not show a clear pattern of preferences and was disregarded in the analysis of preferences). The majority (9 visually impaired and 10 sighted participants) indicated that they preferred rougher substrates over smoother substrates (see Figure 2 for the roughness values of the substrates). A minority (5 visually impaired and 4 sighted participants) preferred smooth substrates over rough ones. On this basis, it was possible to assign the participants to one of two preference groups: rough or smooth.

The participants ranked all the substrates on a 7-point scale, assigning more points to highly preferable substrates. Figure 4 shows the mean ranking scores of the two preference groups. The data suggest that there is an interaction between the type of substrate and the preference group. Multiple Wilcoxon signed rank tests (with a significance level of $p < .0024$, according to a Bonferroni correction for multiple comparisons), were used to explore differences in preference among the substrates. There were no significant differences in the preference for substrates among those in the smooth-preference group. However, the participants in the rough-preference group ranked aluminum and smooth plastic significantly lower than rough paper, microcapsule paper, and Braillon, and ranked rough plastic lower than rough paper and microcapsule paper. To examine differences in preference between the preference groups, we performed multiple Wilcoxon tests (with a significance level of $p < .007$, according to a Bonferroni correction for multiple comparisons). The rough-preference group ranked microcapsule paper, rough paper, and Braillon significantly higher than did the smooth-preference group and ranked aluminum significantly lower.

Time and preference

There was a significant correlation between the *z*-scores for search time and the preference-ranking scores ($r = -0.16$, $p < .05$). Table 2 shows the *z*-scores

for the two preference groups. A two-way repeated-measures ANOVA, using preference groups as a factor, was conducted to investigate differences in exploration time for the two preference groups. A main effect was found for type of substrate ($F(6, 156) = 7.15$, $p < .01$). However, no main effect was found for preference group on exploration time ($F(1, 26) = 0.001$, $p = .97$), and no interaction was found between preference group and type of substrate ($F(6, 156) = 0.69$, $p = .66$).

Discussion and conclusions

In this study, visually impaired and sighted participants performed a search task on seven substrates. Their search time was measured, and they ranked the substrates on the basis of their individual preferences. In general, the participants explored paper substrates faster than they did plastic and aluminum substrates. This finding may be related to the characteristics of the surfaces, such as roughness and absorbency. The plastic and aluminum substrates were smoother and less absorbent, which may have caused the participants' fingers to stick to them and hence may have slowed down exploration. Most participants not only explored the paper substrates faster, they also preferred them over the plastic and aluminum substrates.

When asked the reasons for their preferences, 18 of the 29 participants reported that they either liked the paper

and rough substrates because they found it easier to move their fingers across these rougher substrates or disliked the plastic and aluminum substrates because they were sticky, which irritated the participants' fingertips and made it more difficult to move across the display. An interesting finding was that 8 of the 29 participants preferred the plastic and aluminum substrates because of these substrates' smoothness, which, they thought, made it easier to move their fingers across the display. Observations suggested that these participants had dry skin or used a light touch and hence may have found it easier to run their fingers across a smooth surface than a rough one. However, the data on exploration time suggest that regardless of their preferences, the participants explored the plastic and aluminum substrates more slowly than the paper ones.

The data suggest a U-shaped relationship between the roughness of a surface and preferences and search time (see Figure 2). Very smooth substrates, such as shiny plastic and aluminum, were explored more slowly and were less preferred than were fairly smooth substrates, such as rough plastic and smooth paper. Rough paper and microcapsule paper, which are rougher, were preferred the most and explored the fastest. Braillon, which was the roughest substrate used in this experiment, had an intermediate score on exploration time and preference. The U-shaped relationship may also explain the apparent inconsistency between the findings of Rowell and Ungar (2003) and of Ekman et

al. (1965). Because the textures used in the latter study were considerably rougher than were those used in our studies, they may have been in the range of roughness in which preference begins to decrease. Another explanation for the inconsistency is related to the purpose of the task. Both in the present study and in the study by Rowell and Ungar, the main task was to scan an image on the substrate. In Ekman et al.'s study, however, the task focused on the bare substrate itself.

Given the U-shaped relationship between the roughness of a surface and performance, it is unlikely that our data can be explained in terms of a difference in roughness between the substrate material and the surface of the symbols (which was of a constant level of roughness and relatively smooth). Previous research (Lederman, 1974, 1981) suggested that the discrimination of roughness increases as differences in roughness increase. If increasing differences in roughness between the symbol and substrate were the main factor that facilitated the identification of the symbols, the participants' performance would be expected to improve as the roughness of the substrate increased. The fact that it did not implies that differences in roughness can, at best, be only one of a number of factors that determine differences in performance across substrates.

The results of this study, which are based on the users' exploration time and preferences, suggest that paper substrates, particularly rough paper and microcapsule

paper, may be the most suitable for the production of tactile maps and diagrams using an inkjet printing method. However, other factors should be considered as well. First, the selection of a substrate depends on the functions of the map or diagram. For example, durable substrates, such as plastic and aluminum, are more suitable for use in public places (for example, a map on the wall of a train station), whereas paper substrates, which are lightweight and can be folded up, can more easily be carried by an individual user. Production cost is another factor in the selection of substrates; paper substrates are usually cheaper than are plastic and aluminum substrates. Still another consideration is the use of maps and diagrams by people with residual vision. The use of residual vision is often hindered by reflection, and matte substrates, which have less reflection, may be more suitable in this respect.

It could be argued that the specific task that was evaluated in this study lacked ecological validity and that the results may not be generalizable to the use of actual tactile maps and diagrams in complex, real-world tasks. However, it seems likely that the relative properties of substrates would have an even greater effect in the context of many map or diagram tasks, in that a reader is likely to spend a greater amount of time with his or her finger in contact with the background material while scanning the display for information. The relative advantages of moderately rough substrates are therefore likely to hold for most tasks involving

tactile displays, as well as for our search task.

The results of this study suggest that surface roughness has an effect on the exploration of and preference for substrates. However, other characteristics of surfaces may also have an effect. First, the absorbency of the material will influence the amount of sweat that remains on the finger and thus the stickiness of the surface. Second, thermal conductivity influences the subjective feeling of temperature; for instance, many participants in this study spontaneously remarked that the aluminum substrate, which has high thermal conductivity, felt cold. Third, softness is considered a robust perceptual dimension of texture (Hollins, Faldowski, Rao, & Young, 1993). Other characteristics that may influence exploration and preferences include elasticity or springiness (Srinivasan & LaMotte, 1995); friction; surface chemistry, such as acidity; and surface energy. More detailed research could indicate which characteristics of surfaces influence the ease of extracting information and the preferences for substrates.

References

Dacen-Nagel, D. L., & Coulson, M. R. C. (1990). Tactual mobility maps—A comparative study. *Cartographica*, *27*(2), 47–63.

Ekman, G., Hosman, J., & Lindström, B. (1965). Roughness, smoothness and preference: A study of

quantitative relations in individual subjects. *Journal of Experimental Psychology*, *70*(1), 18–26.

Heller, M. A. (1989). Texture perception in sighted and blind observers. *Perception and Psychophysics, 45*, 49–54.

Hollins, M., Faldowski, R., Rao, S., & Young, F. (1993). Perceptual dimensions of tactile surface texture: A multidimensional scaling analysis. *Perception and Psychophysics*, *54,* 697–705.

Horsfall, B. (1997). Tactile maps: New materials and improved designs. *Journal of Visual Impairment & Blindness, 91,* 61–65.

Horsfall, R. B., & Vanston, D. C. (1981). Tactual maps: Discriminability of textures and shapes. *Journal of Visual Impairment & Blindness, 75*, 363–367.

Keates, J. S. (1982). *Understanding maps*. New York: Halsted Press.

Lederman, S. J. (1974). Tactile roughness of grooved surfaces. *Perception and Psychophysics, 16*, 385–395.

Lederman, S. J. (1981). The perception of surface roughness by passive and active touch. *Bulletin of the Psychonomic Society*, *18*, 253–255.

Lederman, S. J. (1983). Tactual roughness perception: Spatial and temporal determinants. *Canadian Journal of Psychology, 37*, 498–511.

Lederman, S. J., & Taylor, M. M. (1972). Fingertip force, surface geometry and the perception of roughness by active touch. *Perception and Psychophysics, 12*, 401–408.

McCallum, D., & Ungar, S. (2003). Producing tactile maps using new inkjet technology: An introduction. *Cartographic Journal, 3,* 294–298

Morley, S., & Gunn, D. (2002). *Making tactile graphics*. Hatfield, England: National Centre for Tactile Diagrams, University of Hertfordshire [Online]. Available: www.nctd.org.uk

Perkins, C. (2002). Tactile mapping quality: The Manchester experience. *North West Geography*, *2*(2), 11–17.

Pike, E., Blades, M., & Spencer, C. (1992). A comparison of two types of tactile maps for blind children. *Cartographica*, *29*(3–4), 83–88.

Rener, R. (1993). Tactile cartography: Another view of tactile cartographic symbols. *Cartographic Journal, 30,* 195–198.

Rowell, J., & Ungar, S. (2003). Feeling your way—A tactile map user survey. In *Cartographic*

Renaissance: Proceedings of the 21st International Cartographic Conference, Durban, South Africa [CD-ROM]. Durban: International Cartographic Association.

Srinivasan, M. A., & LaMotte, R. H. (1995). Tactual discrimination of softness. *Journal of Neurophysiology, 73*, 88–101.

Sandra Jehoel, B.Sc., *researcher, Department of Psychology, University of Surrey, Guildford, GU2 7XH, England; e-mail: <s.jehoel@surrey.ac.uk>.* ***Simon Ungar, Ph.D.,*** *lecturer, Department of Psychology, University of Surrey, Guildford, GU2 7XH, England; e-mail: <s.ungar@surrey.ac.uk>.* ***Don McCallum, B.E.,*** *researcher, Department of Geography, Anglia Polytechnic University, Cambridge, CB1 1PT, England; e-mail:<d.j.mccallum@apu.ac.uk>.* ***Jonathan Rowell, M.Sc.,*** *researcher, Department of Geography, Anglia Polytechnic University; e-mail:<j.rowell@apu.ac.uk>. Address correspondence to Dr. Ungar.*

Previous Article | Next Article | Table of Contents

Search JVIB | JVIB Policies | Contact JVIB |

If you would like to give us feedback, please contact us at jvib@afb.net.
